



Principles of innovation to build nutrition-sensitive food systems in South Asia

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ABSTRACT

Innovations within global food systems have contributed to the predicament known as the triple burden of malnutrition – the co-existence of hunger and micronutrient deficiency with the diseases of overnutrition, such as obesity, diabetes and hypertension. We use the case of the triple burden in South Asia to demonstrate analytically that innovation is a double-edged sword, with positive and negative potential, rather than a simple good. To achieve the Sustainable Development Goals that target food and nutrition security and sustainable agriculture (e.g. SDGs 2, 3 and 12), the countries of South Asia need more innovation, but, first, they would also benefit from some intelligent reflection about what innovation means, the directions it should take, and its risks and downsides alongside its benefits. In the present juncture, South Asian countries have an opportunity to learn from the experiences of other developing nations, and choose from alternative options to steer their own course. In this paper, we discuss how innovation has contributed to the present situation and ask how alternative kinds of innovation may enable South Asian countries to escape from the triple burden. We describe a conceptual framework that may be useful for thinking about how innovation pathways can be created and directed towards the goal of improving nutritional outcomes in South Asia. The framework draws attention to the *direction* of socio-technical change, the *distribution* of technologies and their risks and benefits, and the *diversity* of possible innovation pathways (STEPS Centre, 2010). We illustrate these points using examples of innovations in the areas of agricultural production, value chain interventions, and policy and institutional reforms.

1. Introduction

Innovations of many kinds have transformed the systems and practices of food production, processing, distribution and consumption during the seven decades since the end of the Second World War. In South Asia and other parts of the world, the agricultural Green Revolution (GR) in the latter half of the last century dramatically increased the supply of grains and oilseeds and helped to sharply reduce levels of absolute hunger and food insecurity. However, increasing production and productivity of carbohydrate-dense crops has not eliminated micro-nutrient deficiencies, nor prevented the emergence of non-communicable diseases (NCDs) associated with processed foods and more sedentary lifestyles. Regionally and globally, human populations are afflicted by a ‘triple burden’ of malnutrition – the paradoxical co-existence of hunger and micronutrient deficiency on one hand with diet-related NCDs such as obesity, diabetes and hypertension, on the other (WHO, 2018). Millions of people have been fed, yet hundreds of millions are still food insecure, and two billion people

suffer from micronutrient deficiencies (IFPRI, 2016; Spielman and Pandya-Lorch, 2009).

At the same time, intensified farming practices inflict heavy costs on the carrying capacity of agro-ecosystems, including the pollution of waterways and waterbodies, lowering of water tables and the salination and erosion of soils (Campbell et al., 2017; Vlek et al., 2017). Modern agricultural methods depend heavily on the consumption of non-renewable petrochemicals, and emit large volumes of greenhouse gases (Hallström et al., 2017). Moreover, despite this huge investment in production, vast quantities of good food are wasted at every step of the chain between farmers’ fields and consumers’ waste bins (Spiker et al., 2017; Stuart, 2009). Meanwhile, rural communities in both the global North and South are under great strain, as farmers and farm workers struggle with low producer prices, inadequate incomes, and the destruction of rural social networks. In South Asia as in other regions, farming communities are afflicted by symptoms of economic and psychological stress (Vasavi, 2009, 2012).

To achieve the Sustainable Development Goals (SDGs) that target

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food and nutrition security and sustainable agriculture (e.g. SDGs 2, 3 and 12), the countries of South Asia need more innovation. However, they will also benefit from intelligent reflection about what innovation means, the directions it should take, and its risks and downsides alongside its benefits. Fortunately, in the present juncture, South Asian countries have an opportunity to learn from other developing nations and developed countries, and choose from alternative options to steer their own course.

In this paper, we explain how previous waves of innovation in South Asian agricultural and food systems have combined to create the present situation, and we suggest how alternative kinds of innovation may enable South Asian countries to escape from the triple burden of malnutrition. We draw upon recent contributions to the literature on responsible research and innovation (RRI) to argue for a reflexive and accountable approach to shaping the development and application of new technologies within agri-food production, distribution and consumption systems (Owen et al., 2012; Stilgoe et al., 2013). We present a conceptual framework that will help policy makers to think about how innovation pathways might be created and directed towards the goal of improving nutritional outcomes in South Asia. The framework draws attention to the *direction* of socio-technical change, the *distribution* of technologies and their risks and benefits, and opening up a *diversity* of possible innovation pathways (STEPS Centre, 2010; Stirling, 2009). We illustrate these propositions using examples of innovations and socio-technical changes from the Leveraging Agriculture for Nutrition in South Asia (LANSA) research consortium,¹ as well as other documented cases, in the areas of *agricultural production*, *value chain interventions*, and *policy and institutional reforms*.

In the discussion that follows, we acknowledge that the countries of the South Asian region are heterogeneous politically, economically, institutionally and agro-ecologically. Approaches to strengthening the linkages between agriculture and nutrition are unlikely to be fully generalisable across South Asia. To successfully improve nutrition, interventions need to account for specific local and national contexts and dynamics.

2. Innovation: A development buzzword

Innovation is a development sector ‘buzzword.’² Governments, policy makers, entrepreneurs and media pundits expect ‘innovation’ to deliver economic growth and solve humanity’s most pressing problems. Academic researchers, policy analysts and civil servants strive to discover the mechanisms that will trigger processes of invention, discovery and experimentation, and spread new technologies – conceived principally as novel products, practical methods and technical processes – to transform industry, service delivery, livelihoods and consumption patterns. In agri-food systems, new technical artefacts, consumables and techniques, such as crop varieties, chemical inputs, cultivation methods, harvesting equipment, storage facilities, food processing machinery, packaging materials, distribution networks, retail and food-service formats and tracking systems, are called upon to deliver better outcomes in terms of efficiency and productivity, food quantity and quality, product safety and nutrition.

This widespread appeal to innovation and novel technologies conforms with everyday usage, where technology is commonly understood to mean machines, devices, gadgets and software, and very often conflated with the latest ‘cutting edge’ technical applications, such as information and communication technologies (e.g. smartphones and tablet computers), satellites and drones (e.g. in precision agriculture), and

biotechnology (such as transgenic and genome-edited organisms). In the narratives of policy makers and social entrepreneurs, these materially embodied avatars of innovation and ‘tech’ are often loaded with an intrinsically positive value, conflated with ‘progress.’

There are several problems with this perspective. We highlight two of them here. First is the risk of technological determinism, where a technocentric framing of innovation tends to overestimate the potential of technical artefacts, networks and systems to determine (beneficial) outcomes. In reality, technical artefacts and systems do not possess momentum, directions or destinations of their own. They are driven and steered by interacting social, economic, political and institutional forces and processes (Leach et al., 2010). They are not value-free, but reflect the values of contending actors and institutions that help to drive and steer them. Second, which is a related point, the deterministic perspective on technology as embodied in technical artefacts neglects, or strongly downplays, the agency of human beings, which is enabled and constrained by relations and interactions with networks of other entities across their social and material worlds, including other humans, nonhuman living organisms, and objects and tools of many kinds, including documents, laws, contracts, discourse, and cultural frameworks (Callon and Law, 1997; Latour, 2005). Within the LANSA consortium, we have adopted a perspective on technology and innovation that places human agency and practice at its centre, which allows us to explore innovation and technology within South Asian agri-food systems as the purposeful activity of people and organisations, conducted and expressed through enabling and constraining interactions among people, plants, animals, materials and their agro-ecosystems (Glover, 2017). We contend that this approach helps to avoid the trap of technological determinism, particularly the analytical error of assuming that innovation is necessarily loaded with a positive value. We expand on these propositions and justify our approach in the following sections of this paper.

3. Innovation and the triple burden of malnutrition in South Asia

The Asian GR was an interlocking set of industrial, technical, infrastructural, policy and socio-economic changes that transformed South Asian farming practices, rural landscapes, patterns of land use and ownership, the livelihoods, lifestyles and employment opportunities of rural people and communities, the diets of rural and urban consumers, patterns of trade, and other aspects of regional and national agri-food systems (Conway and Barbier, 2013; Das, 2002; Patel, 2012). Classical portrayals of the GR emphasise its transformative impacts on food production and crop yields, and stress the revolutionary effect of these changes on household-level, national and regional food security and the near-elimination of extreme forms of hunger (Evenson and Gollin, 2003; Hazell, 2009). The GR is often also credited with raising rural incomes and reducing poverty, although poverty and inequality still prevail (Das, 2002; Freebairn, 1995; Pingali, 2012).

What is undeniable is that a great deal of innovation and technological change occurred during the GR period in South Asia, not only in farm production and input supply but in value chains and consumption practices; yet, forms of food insecurity and malnutrition still survive in the region, as they do in other regions: poor people often still consume diets that lack a diverse range of nutritious foods, and micronutrient deficiencies are still prevalent (Dame and Nusser, 2011; Headey and Hoddinott, 2016; Jewitt and Baker, 2007; Pingali, 2012). The GR favoured the production of a narrow range of staple crops, especially the grain crops rice, wheat and maize, for which modern, high-yielding varieties were available. Crop improvement strategies typically focused on quantitative traits, particularly yield and fertiliser responsiveness, rather than qualitative traits such as micronutrient content (Stein, 2010). The nutritional value of staple crop cultivars declined as they passed through scientific breeding programmes that focused on yields rather than quality traits (Hussain et al., 2012a, 2012b). The GR did little to promote, and indirectly discouraged, the production or

¹ www.lansasouthasia.org (accessed 2 July 2018).

² For example, see an enthusiastic blog post by Michael Møller, Director General of the United Nations Office at Geneva (Møller, 2016). In another blog, academic David Lewis offered a sceptical perspective on the innovation ‘fad’ in development (Lewis, 2012).

consumption of nutritious traditional crops, such as millets and pulses. Many consumers benefited from falls in the prices of staple foods, which sometimes resulted in increases in dietary diversity and the consumption of nutrient-dense foods, but dietary diversity actually decreased for some populations as traditional crops, leafy vegetables and fish disappeared from production systems, and consumption of some micronutrient-rich foods fell as these products became relatively more expensive. As a consequence, the GR's effects on micronutrient nutrition were complex and indirect, and often negative (Gopalan, 2013; Pingali, 2012).

Agri-food systems in the region have continued to be transformed, in the post-GR period, by interlinked processes of globalisation and innovation in food production systems, value chains, retail formats and consumption practices, with improvements in the choice and quality of foods available to some consumers, safer methods of food processing and packaging, and so on. However, the transformation of South Asia's agri-food systems has also led to significant negative effects on the environment, as well as adverse outcomes for the nutritional status and health of many consumers. Moreover, the positive and negative consequences of agri-food system change were unevenly distributed across men, women, children and adolescents, urban and rural populations, producers and consumers, rich and poor (Qaim, 2017).

Today, malnutrition of various kinds remains a stubborn problem in the region (Gómez et al., 2013). While rapid advances were being achieved in East and Southeast Asia, South Asia (alongside sub-Saharan Africa) did not see sharp reductions in the prevalence of micronutrient deficiencies (Beall et al., 2017; Muthayya et al., 2013). A 'nutrition transition' has resulted in substantial increases in the intake of sugar, salt and saturated fats, resulting from reduced consumption of small grains, pulses, vegetables and fruits and increased consumption of meat, oil and processed foods (Khan and Talukder, 2013; Misra et al., 2011). The triple burden is recognised as an urgent public and policy challenge facing South Asian societies, young people, and those concerned with public health and national economic development (Kulkarni et al., 2017; Meenakshi, 2016; Shankar et al., 2017).

Many factors have contributed to the nutrition transition and the triple burden of malnutrition. Increasing consumption of processed foods and fast food, especially but not exclusively among more affluent, urban populations, combined with the influence of intensified marketing and advertising, have had a large impact (Gulati and Misra, 2014; Johnson et al., 2017; Joseph et al., 2015; Mistry and Puthusery, 2015). Major innovations in food value chains and retail formats, including supermarkets and small rural retail outlets, is helping to spread processed, packaged food products even to poor communities in affordable pack sizes (Gómez and Ricketts, 2013; Reardon, 2015).

It is important to recognise that the nutrition transition itself is a kind of innovation, and the triple burden of malnutrition is an outcome of previous rounds of innovation, manifested in waves of society-wide change in socio-technical practices (Gómez et al., 2013). However, in some respects India and other South Asian countries are further behind in this set of interlinked trends compared to countries in East and Southeast Asia, with respect to the supermarket revolution, the shift towards unhealthy diets, and the spread of diet-related NCDs (Baker and Friel, 2014; Gómez and Ricketts, 2013; Reardon, 2015).

Recent historical analysis has suggested that the policies and strategies underlying the GR were not designed to tackle food insecurity among poor people in poor countries. The GR was an extension of Cold War geopolitics, which involved US-based philanthropic foundations in a partnership with the US government to resist the spread of communist regimes (Cullather, 2010; Latham, 2010; Patel, 2012; Perkins, 1997). The GR is more convincingly explained as a way of achieving other goals, in the geopolitical context of the Cold War: boosting production of globally traded agricultural commodities; growing markets for industrial inputs; tying countries into international relationships of aid and trade; and inducting peasant farmers into the capitalist economy (Harwood, 2012; Saha, 2013; Saha and Schmalzer, 2016; Subramanian,

2015).

Bearing in mind these historical facts, policy makers and other stakeholders should recognise that, if future innovations and socio-technical change pathways for agri-food systems South Asia are to tackle malnutrition and achieve the SDGs, they should be designed with nutrition foremost. In the remainder of this paper we explore some design principles, informed by a set of analytical questions, that can guide innovations in South Asian agri-food systems to produce better nutrition outcomes.

4. Diverse innovation pathways

In popular, media and political discourses, the notion of innovation is often invested with an intrinsically positive value. Alternatively, technological progress is sometimes portrayed or perceived as irresistible. The direction of change is rarely posed as a question for debate. These discursive framings of innovation and progress disempower critique, since it is hard to question a process that has been framed as desirable, or to resist an outcome that is generally understood to be inevitable. This logic allows proponents of particular directions and destinations of scientific and technological change to depict these as natural, inescapable, or generally preferred. People who criticise particular visions of progress may find themselves portrayed as anti-social elements or cranks, opponents of science and technology, or obstacles to the betterment of humankind (Jansen and Gupta, 2009). However, the logic is flawed. In reality, the future is indeterminate; progress is rarely linear or uni-directional; moreover, from any given point in history, many different pathways of social and technological possibility are potentially available (Leach et al., 2010; Stirling, 2009).

The implications and ramifications of alternative socio-technical pathways may be radically different, and their consequences may be unevenly distributed across the members of a society or community. These qualities of indeterminacy and unevenness make it legitimate and proper to open the directions of socio-technical change to democratic debate and scrutiny. Traditional economic analysis usually prioritises quantitative and structural approaches to the analysis of technological change, focusing on increases in total output and productivity, indicators such as the efficiency of innovation, the performance of innovation systems, the competitiveness of innovators (e.g. early adopters, laggards, firms 'catching up'), the rate of technological change, and the scale of technological expansion (Dosi, 1982; Geels, 2002; Lundvall, 2007; Perez, 2010; Rogers, 2003). Over the past few decades, some researchers in the areas of science policy, innovation studies and related fields, such as science, technology and society studies (STS), have developed new theoretical, conceptual and normative frameworks, which encourage policy analysts and decision makers to acknowledge, more openly and transparently, the quality and indeterminacy of technological change and the values which are at stake in selecting the directions of change (Leach et al., 2010; Stirling, 2009). Scholars have demonstrated how innovation trajectories are driven and shaped by networks of social and economic actors and institutions, including finance, regulation, politics, popular sentiments, consumer attitudes, and economic ideologies (Bijker et al., 1987; Bijker and Law, 1992; Callon, 1987; Hughes, 1987; Latour, 2005; MacKenzie and Wajcman, 1999).

This diverse body of work has also shown how the possibilities of technological change may be opened up and closed down by political processes, and how particular technological trajectories come to be 'locked in' by path dependency, through the shaping of expectations, feedback loops, the obduracy of materials and infrastructure, and the influence of incumbent powerful actors (Leach et al., 2010; Stirling, 2009). Broadly speaking, such approaches agree that analysts of technological change should adopt more actor-oriented approaches to technology and technological change (Biggs, 1990; Long, 2001; Richards, 1985), paying attention also to the roles of innovation intermediaries and brokers (Klerkx et al., 2009) and to the distribution of

agency within networks of people and things in specific environments (Fatimah and Arora, 2016; Stirling, 2011).

Some readers might object to our eclectic and inclusive approach to this literature, which encompasses a range of critical and social constructionist approaches that were produced by scholars from different disciplines and traditions, working independently of and sometimes in friction with one another. However, for the purposes of the present article, we contend that it is not necessary to discriminate between these, admittedly distinct, perspectives and schools of thought. We share the view of Sovacool and Hess (2017) that scholars and policy analysts ought to broaden their conceptual debates and ‘move beyond science, engineering and economics as preferred “cognitive resources”’. Therefore, our aim is to take notice that these alternative approaches to understanding technology and innovation are often neglected in mainstream discourses and concepts of technology and innovation. A consequence is that established methods of operationalising and evaluating technological change are prone to the linearity and determinism we have mentioned above.

Our specific purpose is not to advocate for or against one or other of these alternative conceptual approaches to understanding technology and technological change, but to propose a simple analytical framework which poses a series of questions about interventions that aim to change technology in order to produce better outcomes. We seek to contribute to ongoing discussions among policy analysts and practitioners about how to ‘catalyse a new conversation about how development stakeholders ... engage in the multiple pathways to transformational change’ (CSIRO and CGIAR ISPC Secretariat, 2017: 6; Hall, n.d.). In this paper, our focus is on interventions in agri-food systems that are intended to improve nutrition.

We adopt an explicitly normative approach to the responsibilities and accountability of the actors who promote technological change. In recent years, ‘responsible research and innovation’ (RRI) has emerged as a framing concept for a reflexive and accountable approach to the conduct and governance of scientific research, technology development and socio-technical innovation for the benefit of society (Owen et al., 2012). The RRI framework has been developed to assist with the responsible governance of ‘emerging’ technologies, such as nanotechnology, artificial intelligence and genome editing, whose future uses and wider ramifications are intrinsically hard to predict, but potentially significant and consequential (Stilgoe et al., 2013). Not all of the technologies that may be applied within South Asian agri-food systems in the next few decades are as unprecedented or carry such revolutionary potential, although some certainly do, such as genome editing (Ma et al., 2018), synthetic meat products (Bhat et al., 2017) and nanotechnology applications in food and the food value chain (Sozer and Kokini, 2009). Nonetheless, other technological applications and processes of socio-technical change, which appear less extraordinary and more incremental – often by virtue of their technical components being already familiar in other places or contexts – may still involve many actors in local innovation processes, which will generate profound and sweeping changes in agriculture and food systems over time; a historical example is the enormous expansion of dairy production and consumption in India (sometimes known as the ‘white revolution’) (Kurien, 2007).

One analytical approach to underpin a responsible approach to innovation and the governance of technology, is to bring to the surface the ‘three Ds’ of innovation: its *direction*, its *distribution*, and its *diversity*. The ‘three Ds approach’ or the ‘pathways approach’ was articulated by Stirling and colleagues at the ESRC STEPS Centre located in Brighton, UK, in a ‘new Sussex manifesto’ for innovation, sustainability and development (STEPS Centre, 2010; Stirling, 2009). The STEPS pathways approach suggests that observing and evaluating the direction of technological change means attending to ‘vector’ qualities rather than only ‘scalar’ quantities: that is, how technical and social arrangements are being configured and shaped in particular ways over time, and how costs, benefits and risks are being (re)distributed differentially among

people and across networks, rather than merely how fast things are changing or how many people, organisations or systems are being affected by change. It entails examining which technological pathways are being selected or prioritised, and which alternative pathways are being neglected, closed down or sidelined (STEPS Centre, 2010; Stirling, 2009).

In the context of agri-food systems, this injunction to attend to the current and potential directions of technological change means to consider why current configurations of farming, processing, distribution, retail, policies and regulations are creating a triple burden of malnutrition in South Asia. Concretely, it means examining why South Asian agri-food policies, programmes and enterprises are currently promoting the production of staple cereals and oils rather than nutritious vegetables, pulses and small grains, and stimulating the consumption of unhealthy quantities of sugar, salt, and unhealthy fats.

Attending to distributional issues means examining how the costs, benefits and risks entailed by a particular technological pathway are distributed among the stakeholders in a society or community. It involves asking: Who are the winners and losers? Which values are being promoted and which are being overlooked? This distributional analysis raises questions of equity and social justice, as well as questions of efficiency and strategy: Are the costs being borne by those most able to bear them? Are they being paid by those who also stand to benefit from the change in other ways? Are the innovators themselves causing others – including society at large – to bear the costs and risks of their innovation, while they reap the benefits (Stirling, 2009)?

For agri-food systems, a focus on distributional questions demands that inequality and the diverse interests, situations and predicaments of a heterogeneous population are taken explicitly into account. Examples from the history of the GR and post-GR periods help to demonstrate that governance and policy approaches that attempt to solve the triple burden using a monolithic, undifferentiated approach – such as focusing on yield in crop breeding programmes at the expense of nutrient content – are likely to fall short, and may also produce unintended negative consequences for the population as a whole or for some people and groups. To tackle the triple burden in South Asia, a spectrum of agri-food innovations is needed that can address the diverse causes and consequences of the nutrition problem across multiple sectors, levels and scales of the agri-food system, encompassing basic research, crop breeding and input supply, on-farm production and natural resource management practices, processing, packaging and distribution systems, retail formats and consumption habits, and other aspects. Instead of a standardised, homogenising approach based on a conception of a singular impact pathway, diverse innovations will be needed that can address complex, multiple, specific, local pathways affecting particular populations – richer and poorer consumers; urban and rural areas; men and women; adults, infants and adolescents; inhabitants of particular regions; and so on.

Promoting or preserving a space for a diversity of technological options and pathways will ensure that society does not generate risk or create harm by ‘putting all its eggs in one basket’. It also recognises the plurality of any society or community, a spectrum of different individuals and groups with divergent interests and values. These are difficult to satisfy or respect if all members of the society are driven in the same, singular direction. A diversity of technological pathways is also valuable in itself, as a key resource underpinning the robustness and resilience of social and technical systems. Encouraging diverse technological pathways will entail trade-offs such as higher transaction costs and an increase in system incoherence, but these sources of friction may be compensated by other benefits, such as an increase in creativity and innovation through the interaction of different practices, knowledge systems, institutions and cultures (Stirling, 2009).

For policy makers facing the challenge of the nutrition transition and the triple burden of malnutrition in South Asia, the injunction to promote diversity in innovation implies that solutions are not sought only from certain sources, such as agriculture ministries, agribusiness

Box 1

Analytical framework to assess innovative propositions (Glover, 2017).

1. What is the basic approach involved in the intervention?
 - What is the essential technical (material, practical) change envisaged by the intervention? Is the change sufficiently clear and coherent conceptually to be summarised in a few sentences?
 - Does the intervention reflect an (implicit) ‘impact pathway’ or ‘theory of change’?
2. What forms of practice or behaviour are envisaged if this intervention/innovation is taken up?
 - What new activities would be introduced? What existing activities would be eliminated or changed?
 - Are the envisaged changes in practice small and simple, or extensive and difficult?
 - Are the changes concentrated in time and space or do they ramify across a wide area and/or an extended timescale (entailing knock-on effects for other activities)?
3. Who is expected to practise or implement this technology?
 - Who are the key individuals, groups or organisations envisaged as the principal practitioners (and beneficiaries) of the proposed new technology?
 - Where are they situated geographically, culturally and economically? What resources do they have at their disposal?
 - How much power or agency do they have to effect change? What is their capacity to handle and manage risk?
4. What material inputs may be required?
 - What kinds and quantities of materials, resources, equipment or tools will be needed in order to take full advantage of the opportunities presented by the technology?
 - Does the new technology require additional supplies of inputs such as land, chemical fertilisers, machinery, irrigation water, and so on? If so, are these resources readily available? Who will procure and/or supply them, and how?
5. What information, knowledge or skills are required?
 - What kind and level of know-how or guidance is needed in order to take full advantage of the opportunities presented by the technology? Are the required skills specialist or general?
 - Who will supply the necessary information, training or advice? How?
6. How large is the actor—network implicated in the change? How is it composed?
 - How extensive is the network of actors and resources likely to be engaged or affected by the proposed technological change?
 - How evenly are power and agency distributed through the network? Which of the nodes (actors, resources) are unique and essential and which are generic and interchangeable?
7. How does the intervention create cultural changes and redistribute power?
 - Who are the likely winners and losers of the intervention? What implications does this distribution have on the motivations and cooperation of different stakeholders and interest groups?
 - How may the benefits be maximised and widely shared, and how might losses be minimised and compensated?
 - How do these considerations affect the likelihood of implementation, and realising the advertised benefits of the proposed technological change?

inputs suppliers, fiscal instruments (e.g. farm or consumer subsidies), public education programmes, or particular scientific disciplines (e.g. crop breeding). Instead, there is intrinsic value in seeking out and creating spaces for multiple actors, ideas, programmes and initiatives to contribute to innovation in different ways. This enables society to benefit from the potential of crowd-sourcing ideas; to combine the capabilities of different actors in an innovation system; and to create diverse solutions for different niches.

Tackling the challenge of the triple burden in South Asia will require action across entire chains from production to consumption, including aspects upstream of farms, such as input supply, crop breeding research, and financial services. Drawing upon the guiding ‘three Ds’ principles of the pathways approach, in the LANSa programme we proposed a set of practical questions that could help analysts and policy makers to think about the design and implementation of innovative measures – including technical, practical, policy and institutional interventions – that could be designed to achieve better outcomes for nutrition in South Asia (Glover, 2017). These are presented in Box 1.

The questions recognise that innovation necessarily comprises change in the activities and practices of a range of actors. The questions are intended to help the designers and implementers of interventions to identify the actors who are implicated within a proposed change process which is intended to improve nutritional outcomes from agri-food systems. The questions seek to understand how innovations might work for specific situations, identify the resources required, and reveal the challenges of system coordination. In the next section, we look at how these guidelines might be applied to the study of existing, and

evaluation of prospective, innovations intended to improve the nutritional outcomes.

5. Examples from LANSa and other literature

Table 1 presents a summary analysis of interventions that have sought to organise and focus the activities of people, natural resources, inputs, tools, institutions and relationships to improve nutrition through agriculture and value chains in South Asia. The table is derived from a previous version (Glover, 2017) and the analysis in this section is based on the same working paper. The cases presented in the table were drawn from examples studied by contributors to the LANSa programme, as well as additional cases from the wider literature relating to the agriculture—nutrition nexus in South Asia.

Table 1 includes 11 interventions of various kinds, ranging from measures to encourage the cultivation of vegetables and keeping of small livestock and poultry at farm household level, to village-level interventions designed to make farming systems within a whole rural community more nutrition-sensitive, to the promotion of biofortified crops and the transgenic biofortification of rice, to the commercialisation of nutrient-rich and fortified processed foods, and interventions intended to encourage the cultivation and consumption of nutritious traditional millets.

In each case, the essential concept underlying the intervention is generally quite easy to state (Table 1, column 3). However, the wider implications are often much larger and the range of actors to be engaged may be wide and diverse. For example, encouraging rural

Table 1
Summary examples of interventions/propositions for technological change to strengthen agriculture—nutrition linkages in South Asia.

Example interventions	Essential concept (implicit impact pathway or theory of change leading to improvements in nutritional outcomes)	Who is expected to practise the technology? (principal or emblematic practitioners)	What behaviours or practices are expected to change?	What material inputs are needed?	What information, skills and knowledge are required?	Extent of the actor—network to be engaged (scale of the change)	Scope of the change (complexity of the transformation)
1 Home/kitchen gardens	Stimulating/increasing domestic production of nutrient-dense food crops leads to increased consumption of nutritious foods, raise incomes	Rural (farm) HHs, especially women	New or expanded cultivation of nutrient-dense crops in home gardens; especially by women	Suitable, accessible land. Seeds Water Other inputs e.g. fertiliser, pest control equipment	For crop cultivation: knowledge and skills of FV cultivation (sowing, care, harvesting) For consumption: knowledge about FV processing, storage, food preparation; nutritional content and health benefits	Agricultural extension service; community support and health workers	Modest changes in practice largely under control or within domain of HHs. Cultural change around gender roles/empowerment of women
2 Collective vegetable gardening by young women	Stimulating small-scale production of FV will empower young women, increase production and consumption of nutritious FV, raise incomes	Young rural women cooperating in small groups	Young women form groups, take up FV production for consumption and sale Increased consumption of nutritious FV at HH level	Land for young women to cultivate Seeds, fertilisers; Material for greenhouses and polytunnels, farm tools and implements	Knowledge and skills for FV cultivation and consumption	Small groups of women supported by families and wider communities; trained and advised by agricultural extension officers and technicians	Substantial new activities involving formation of new groups, allocation of land and resources, learning of new skills
3 Small livestock/poultry (e.g. ducks, chickens.)	Encouraging rural HHs to undertake or improve small livestock/poultry husbandry leads to increased consumption of nutritious foods, higher incomes	Rural HHs, especially women and young people	Improvement/expansion of livestock/poultry husbandry and consumption of livestock/poultry products	Healthy and productive chicks/ducklings/breeding goats; feeds; vaccines	Veterinary services and livestock husbandry advice	Agricultural extension services; community health workers; NGOs; veterinary services. Sellers and consumers in the market	Modest to substantial changes of practice within HHs; Dependent on technical services and public market facilities
4 Nutrient dense/biofortified crops (e.g. OFSP, high-zinc rice)	Cultivation of new, nutrient-dense (varieties of) food crops leads to increased consumption by producers and consumers	HHs, especially women (cultivating and cooking nutrient-dense food crops)	HHs adopting or increasing cultivation and consumption of nutrient-dense food crops	Clean planting material of nutrient-dense varieties Other farm inputs (e.g. fertilisers, fungicides, water)	Training and information about cultivation practices, storage and cooking precautions, nutritional benefits	Seed suppliers; agricultural extension services Community health workers/NGOs Food preparers and consumers	Potentially simple (e.g. substitution of nutrient-dense varieties); more complex where intervention entails totally novel crop/food
5 Food product fortification (e.g. fortified oils, grains; Tiger biscuits [India]; Shakti Doi yoghurts [B'desh])	Fortification of basic food products (e.g. flours and oils) or processed food products (e.g. snack foods) leads to improvements in nutritional outcomes	Food processing industry (major food companies; small-scale millers, etc.) Regulation by state (compulsory fortification; quality and safety standards)	Manufacturing and marketing of fortified foodstuffs and processed food products; consumers buying and using fortified foods	Micronutrient additives (fortificant premixes) Processing equipment (e.g. mixers)	Skills and equipment production and quality control of fortified products Health advice/marketing info. to consumers	Post-farm value chain, including retailers and consumers May include small-scale grain millers, big-brand food companies	Modest technical changes, largely within control of processors, but requiring capital investment and ongoing input costs
6 Biofortified transgenic crops (e.g. Golden Rice)	Altering genetic characteristics of staple crops creates more nutrient-dense foods, increases consumption of micronutrients	Farmers cultivating biofortified transgenic crops; Consumers choosing and consuming them	Plant breeders and seed companies developing and supplying biofortified crop varieties; Farmers choosing to plant them; Value chains, consumers choosing biofortified food products	Biofortified seeds, including transgenic varieties	Information and training about novel traits: how to cultivate the crops; how to process/store them after harvest. How to cook them (modified methods to preserve distinct characteristics?).	Whole value chain (from basic R&D, breeding and input supply to consumption), including regulation, marketing: Public AR4D system; private input dealers and distributors; food processors, retailers; regulators; consumers	On-farm impacts potentially minimal (substitution of new variety); In seed system and post-farm value chains, implications potentially very large (segregation, labelling, monitoring)
7 Nutrient cycling using biochar	New methods for processing and combining (a) crop	Rural HHs including men and women,	Adoption of new practices/processes to produce	Biomass (crop residues and other vegetation) for	Initial training and guidance on entire system, especially (a)	Men and women within HHs; farm labourers	Substantial changes in activities, skills and (continued on next page)

Table 1 (continued)

Example interventions	Essential concept (implicit impact pathway or theory of change leading to improvements in nutritional outcomes)	Who is expected to practise the technology? (principal or emblematic practitioners)	What behaviours or practices are expected to change?	What material inputs are needed?	What information, skills and knowledge are required?	Extent of the actor—network to be engaged (scale of the change)	Scope of the change (complexity of the transformation)
(Biochar Urine Nutrient Cycling for Health, BUNCH)	residues and (b) animal urine will capture nutrients that will (c) be applied as fertiliser to the crop root zone using new crop establishment techniques; (d) improving crop productivity and nutritional profile of crops grown on poor soils	likely organised into groups of neighbours	biochar, collect urine, combine them, and apply resulting nutrient-charged biochar to plant root zone	burning; kilns for controlled (oxygen-limited) burning to create biochar; urine collected from livestock; vessels for storage and transport of urine and biochar	constructing kilns, (b) controlled burn, (c) application of biochar to root zone	External support from trainers and technicians	organisation, but largely within HHs or small groups
8 Farming Systems for Nutrition (FSN)	Reorganisation of farm production systems at village scale, in order to diversify cropping patterns, increase production and consumption of nutritious foods	(a) Farmers and village communities (b) Agricultural researchers and extensionists	In production: Changes in farm- and village-level crop and livestock mix In consumption: HH and individual dietary changes (quality and diversity)	Land. New crops, improved seeds; other farm inputs e.g. fertiliser, pest-control equipment and methods	Guidance and information on diversified crop and livestock management techniques; nutritional information and dietary advice	Farmers, labourers, HH-members Public sector AR4D and extension system; Agri-input dealers and distributors; Community health workers; NGOs	Context-dependent; potentially extensive, involving significant change in land use, cropping patterns, seasonal activities, etc
9 Integrating nutrition advice into agricultural extension platforms	Providing health and nutrition advice through digital platform raises awareness of healthy maternal, infant and young child nutrition (MIYCN) practices, leading to changes in behaviour	Women, especially mothers and people caring for infants and young children	Target population engages with health and nutrition advice delivered via video format, and follows recommended advice	Video-recording and editing equipment; devices for screening and sharing videos; venues to screen videos and hold discussions and training sessions	Nutritional information and guidance; health and nutrition knowledge; Health communications expertise; Film-making expertise	Women carers; Nutrition experts; Community health workers; Communication specialists; film makers	Context-dependent Behavioural changes; potentially extensive, disruptive for women and families dependent on women's labour
10 Promotion of nutritious traditional crops and foods (e.g. millets) ^a	Government-backed NGO interventions to improve production and promote consumption of millets revives cultivation and consumption	State government (provides funds); Coalition of local NGOs & CSOs (implements promotional activities); Tribal communities	HHs in rainfed tribal areas take up improved varieties, cultivation methods and processing technologies	Improved millet varieties; infrastructure for storage and sharing of seeds; millet processing machinery; improved irrigation infrastructure	Awareness-raising activities, nutritional information and dietary advice; agricultural and agro-processing training and advice	Regional NGOs & government agencies; local NGOs/CSOs; farmers, HHs and communities; millet breeders & seed producers; irrigation and extension services	Requires coordination of interventions across scales and sectors. Seeks behavioural, technical and institutional change
11 Inclusion of millets in the PDS (India)	Including millets within the PDS stimulates demand, increases supply, improves accessibility and boosts consumption of nutritious small-grain cereals	State governments procure millets for PDS; Farmers respond to price signals and increase millet production; PDS-eligible HHs purchase and consume more millets	Production, distribution and consumption of millets to increase (relative to rice and wheat)	Millet seeds (increased supply, improved quality?)	Awareness-raising to inform farmers and consumers Advice and guidance on nutritional benefits of millets and dietary diversification	National legislation, state-level policy and implementation; funds for procurement and distribution of grain; farmers and consumers	Simple, one-time change to legal/policy framework (e.g. National Food Security Act 2013) may trigger extensive reconfiguration of practices

Note: Reproduced with permission from (Glover, 2017). Row 10 is a new addition by the authors. Key: a.k.a. = also known as; CSO = civil society organisation; FV = fruit(s) and vegetable(s); HH = household; NGO = non-governmental organisation; PDS = Public Distribution System (India); OFSP = orange-fleshed sweet potato; SP = sweet potato; VAD = vitamin-A deficiency.

^a We are grateful to a peer reviewer for drawing this case to our attention.

households to take up, expand or improve the production of highly nutritious foods, such as fresh vegetables, eggs, milk or meat is a conceptually simple intervention, intended to improve household nutrition directly (through consumption) and indirectly (by raising incomes). However, the intervention requires various supportive contributions to be in place, including markets for additional inputs and outputs, agronomic training and advice, and health- and nutrition-related information and guidance. Good sanitary practices may be especially necessary in relation to animal production, consumption and marketing. Although the production system is largely under the control of households, it depends also on external inputs that need to be available on an ongoing basis, such as seeds, ducklings, vaccines, feed supplements, and veterinary services.

Schemes to encourage an entire community, or groups within it, to cultivate nutritious foods (e.g. rows 2, 8 and 10 in Table 1) entail the participation of many community-members and possibly also the creation of new associations, such as cooperating groups of young women (Row 2) or farmers in tribal communities (Row 10). These moves could disturb traditional associations and/or cultural norms, and may only succeed with the support of gate keepers and community leaders.

Another intervention that appears deceptively simple is the effort to encourage farmers to cultivate and consumers to eat more of a specific type of nutritious vegetable. An example is orange-fleshed sweet potato (OFSP), which is rich in beta carotene, the dietary precursor of vitamin A (Table 1, row 4). The major challenges for such an intervention are not only agronomic, but involve working on both supply and demand aspects of the system simultaneously. To achieve the targeted improvements in vitamin A status, the beta-carotene profile of OFSP varieties must be sufficiently high to make a difference nutritionally, but farmers, processors and consumers must also understand how to protect the beta-carotene content during post-harvest storage, distribution and cooking. The bioavailability of beta carotene depends on the general health and nutritional status of consumers and the composition of their diets as a whole (Haskell, 2012). Fundamentally, OFSP varieties must be perceived as good to eat by the target population. The impacts of the OFSP intervention therefore depend heavily on the socio-economic context, as well as complementary communications and guidance to influence the practices of many actors along the value chain.

Row 6 in Table 1 examines a different kind of biofortified crop, namely transgenic Golden Rice. This high-profile example involves genetically modifying rice to express beta-carotene in its grains, as well as its green leaves and stems. Other projects have targeted the levels of micronutrients such as iron and zinc in rice (Brooks, 2010). This case has something in common with the promotion of OFSP, however, the use of genetic engineering means that a much more extensive network of actors and resources must be engaged, including specialised scientific skills and equipment. Genetic engineering has also attracted special regulatory testing and oversight, and stimulated considerable public opposition from some consumers, environmental activists and development campaigners. These features of the innovation mean that the number and diversity of actors involved in helping or hindering the project is large, and so the complexity of delivering the project goals increases. There is a high level of technical challenge in getting rice grains to express beta-carotene at levels significant enough to make a substantial difference to the vitamin A status of people eating the rice (Brooks, 2013; Eisenstein, 2014; Enserink, 2008). Equally challenging is to get the transformed rice varieties to perform agronomically in different rice-growing zones and regions, which has involved an international network of scientific collaboration (Bollinedi et al., 2017). There still remains the challenge of convincing farmers to cultivate the new varieties and consumers to eat them (Bongoni and Basu, 2016).

Table 1 (row 5) also includes examples of nutrient fortification that occur in the post-farm value chain, where food products such as grains and oils are fortified with micronutrient supplements. This type of

intervention need not involve farmers or require changes to existing cultivation systems or food preparation practices and consumption habits by consumers, except in so far as consumers might need to be encouraged to select a fortified product rather than an unfortified one. Otherwise, the only part of the value chain that is really affected is largely under the control of the processing company concerned. Modest external inputs are required, namely supplies of chemical fortificants and the equipment needed to combine them with the foodstuff in question. However, while the technical requirements are relatively simple, the process is not manageable by the innumerable small mills (*chakkis*) that serve the majority of the population, such as in Pakistan and Afghanistan (Ansari et al., 2018; GAIN, 2018).

Some food companies envisage a market for fortified, processed foods as a commercial opportunity, which they have targeted with branded food products. Examples reviewed by LANSAs researchers include Britannia Foods' Tiger biscuits in India and Grameen Danone's *Shakti Doi* yoghurts in Bangladesh (Table 1, row 5). Tiger biscuits are fortified with iron, calcium and vitamins and are sold through commercial channels.³ *Shakti Doi* yoghurts are rich in protein and calcium and contain added zinc, iron and vitamin A and are sold through small shops and directly to consumers through a door-to-door sales network (Sirajul Islam et al., 2017). In such cases, nutrition-related health claims are incorporated within the branding and advertising of the products, which are marketed to middle class consumers and in small package sizes to poorer customers as well. A network of community health workers promotes the health benefits of *Shakti Doi* yoghurts. These commercial fortified foods can be produced and marketed without radically changing the practices of producers, processors and retailers. However, the poorest section of the target population is particularly hard to reach.

Row 7 in Table 1 examines a project that encourages farmers to produce and use biochar as a vehicle to recycle valuable nutrients through the farm system. Biochar can be produced locally, using biomass collected from the local environment. The biochar must be combined with urine collected from livestock. The biochar's porous structure allows it to absorb a very large volume of liquid urine, which is loaded with nitrogen (N), potassium (K) and micronutrients. The nutrient-charged biochar must be dug directly into the root zone of crops as they are being sown or transplanted, because the plant roots need to be in direct contact with the biochar in order to draw out the available nutrients. The biochar system entails a significant reconfiguration of farming operations, including some completely novel practices that impose considerable demands of labour, time, skill and attention. The potential direct benefits in terms of household nutrition may depend on how effectively the biochar system returns valuable N and K to the crop root zone, and how well crop plants take up any additional micronutrients that the nutrient-loaded biochar may provide. If the crop productivity and yield improvements are large enough to generate a marketable surplus, then the technology may also help to improve nutrition indirectly, via increased household income. Although the biochar nutrient cycling method entails substantial hurdles in terms of resources, time, effort and organisation, and a wide network of human and non-human actors, in principle the material resources needed for ongoing management could be readily available within the local farming system or the local environment.

Row 9 in Table 1 examines an integrated approach to delivering health and nutrition advice alongside agricultural extension services. A project in India used modern ICT tools to deliver nutritional information and advice to women, especially mothers of infants and young children (Kadiyala et al., 2016). The connection to agricultural practices was indirect. This type of intervention depends on the provision of material resources including audio-visual equipment and services such

³ <http://britannia.co.in/products/tiger/tiger-glucose> (accessed 15 March 2017).

as electricity, internet and telecommunications, and the financial resources necessary to sustain the intervention, to scale it up, and to reach successive cohorts of young women and new mothers. A range of specialist knowledge is required, including expertise in health and nutrition, and skills relating to health communications and film-making.

The last two interventions in Table 1 are intended to encourage the cultivation, consumption and marketing of millets. Millets are nutritious small-grain cereals, which were traditionally grown in rainfed and semi-arid areas of India, but relatively neglected during the GR, and declined in popularity (Padulosi et al., 2015). In row 10 of Table 1 is an NGO-led initiative that convinced the state government of Odisha, India, to promote millets in tribal districts. In row 11 is a change in policy and the redirection of a public subsidy through legislation that allowed the incorporation of millets within India's Public Distribution System (PDS). The PDS is a long-established scheme that gives poor households access to subsidised grains through 'fair price shops'. Until recently, the PDS covered rice and wheat, while some states also included items such as sugar and kerosene (Balani, 2013). Though the principal reform is institutional rather than technical, the ramifications of the policy and the realisation of its goals necessarily involve other innovations – technical, practical, organisational and institutional – by various actors throughout the food system. The inclusion of millets in the PDS and school midday meal programmes creates a mechanism to stimulate increased consumption of these nutritious and culturally appropriate grains in poor households (Parasar and Bhavani, 2016), although there is a risk that subsidised procurement prices could drive up millet prices in consumer markets outside the PDS (Rajshekhhar and Raju, 2017). With this type of intervention, changes in behaviour are required from both farmers and consumers, but these changes are stimulated with relative ease. The direction of the new policy is largely under the control of government ministers through existing bureaucratic structures, and relatively easy to implement in the context of the existing PDS framework.

6. Discussion

To varying degrees, all the interventions outlined in Table 1 can be criticised for embodying assumptions that are implicitly deterministic and linear, about the role of 'technology' and 'innovation' (in their commonly understood meanings) in producing a targeted outcome (improved nutrition). Using the simple framework of practical questions listed in Box 1, we have shown that the conceptual simplicity of a proposed technological intervention often conceals a much greater complexity. In particular, our approach helps to bring to the surface the range of actors –interacting within institutional relationships – that are implicitly expected by the designers and implementers of interventions to be involved in producing the desired outcomes.

We believe that exposing the complexity of the diverse activities and relationships that would need to be aligned and coordinated, in order for an envisaged outcome to be delivered – even for a conceptually simple change in technology – is a useful and practical reality check, against which such interventions can be assessed before and while they are implemented. Recognising that multiple stakeholders have degrees and kinds of agency in the reconfiguration of socio-technical systems calls for a dose of humility on the part of planners and system builders, especially a recognition that the potential achievement of beneficial outcomes must involve contributions from multiple actors, rather than masterful direction by an omniscient, masterful instigator and controller of change (Ton et al., 2014).

7. Conclusions

We have used the case of the triple burden of malnutrition in South Asia to demonstrate analytically that innovation is loaded with positive, negative and ambiguous potential, rather than a simple good. We have proposed that responsible attention to the direction, distribution and

diversity of innovation pathways can help decision makers to foster an environment in which innovative practices by multiple actors in South Asia could help to change agricultural and food systems in the region and strengthen nutritional outcomes, in ways that could be more equitable, sustainable and resilient. Drawing inspiration from the concept of RRI, we have argued that this would be the responsible and accountable way to proceed. Moreover, we believe that South Asian countries have a window of opportunity to learn from the experiences of other developed and developing countries, in areas such as the 'supermarketisation' of food retail and the expansion of fast food restaurants, in order to steer their own course.

To strengthen the connections between production and nutrition in South Asia, policy makers should adopt an agri-food systems perspective, encompassing innovations in agricultural research, value chain coordination, and food systems regulation. When assessing the potential for particular technology interventions to be successful in tackling specific aspects of the triple burden, sustainably, in specific places and for particular social groups, an actor-oriented perspective is helpful to understand who is being expected to initiate change, reconfigure networks, coordinate action, acquire new knowledge, learn new skills, supply new inputs, and so on.

The 'three Ds' pathways approach, as applied in this paper, recognises that agri-food systems innovations are driven by social actors, economic forces and institutional practices along pathways that have particular directions, with consequences for the distribution of costs, risks and benefits, and for the possibilities and potential directions of future innovations. In other words, the relevant questions to ask about innovation are not only about scale, speed or magnitude, but also about 'vector' qualities: directions and destinations, and their consequences for equity, risk and resilience.

Achieving nutrition security for young and old, women and men, urban and rural, affluent and poor people in South Asia means understanding that different kinds of malnutrition are created for these populations through multiple, specific pathways, and enabling a diverse range of bespoke, local and sector-specific solutions to be created and propagated through the agency of networks of public, private, philanthropic and civil society actors. Meeting the challenge of healthy diets in an increasing and ageing population is not just a matter of food quantity, progressively raising yields and increasing crop resistance to pests and diseases, but attending to the quality of agri-food systems innovation, what pathways will be followed, and how the costs, risks and benefits will be distributed.

Among the challenges facing society in the domain of agriculture for nutrition is a concerted effort by multiple food and nutrition actors in public, private, civil society and philanthropic sectors, to re-orient agricultural and food systems to be more nutrition-sensitive. The SDGs reflect such an aspiration, but innovative governance is required at the global level, to build an effective meta-organisation out of the disparate players (IFPRI, 2018).

Three areas of policy among many can be specified, which exemplify our argument about the importance of attending to the *diversity*, *distribution*, and *direction* of pro-nutrition innovation. First, the principle of *diversity* suggests reprioritising within agricultural research and development programmes from the improvement of starchy staple crops to the improvement of hitherto neglected or underexploited resources and marginalised ('orphan', not marginal) systems. For example, livestock products are important for the nutrition of vulnerable groups such as children, adolescents and young women, however, livestock systems tend to contribute disproportionately to environmental pollution and climate change. Research and development is needed to work out how these trade-offs can be managed.

A focus on *distribution* suggests, for example, that to be effective in reaching rural populations at risk of micronutrient deficiencies, wheat fortification strategies (such as in Pakistan) should work through local *chakkis* (mills) and not just the easy-to-reach industrial milling enterprises which serve the urban population. Finally, a focus on the

direction of innovations in the agri-food system implies that innovative kinds of intersectoral foresight and planning are needed. To create an agri-food system in South Asia that can deliver better nutritional outcomes for diverse populations and contexts, it is necessary to design and integrate solutions that have the potential to produce and distribute not only adequate calories but also micronutrients, combined within healthy and balanced diets, in ways that are both sustainable and resilient.

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References

- Ansari, N., Mehmood, R., Gazdar, H., 2018. Going against the grain of optimism: flour fortification in Pakistan. *IDS Bull.* 49, 57–71.
- Baker, P., Friel, S., 2014. Processed foods and the nutrition transition: evidence from Asia. *Obes. Rev.* 15, 564–577.
- Balani, S., 2013. Functioning of the Public Distribution System. An Analytical Report. PRS Legislative Research, New Delhi, IN: PRS. www.prsindia.org/administrator/uploads/general/1388728622~TPDS%20Thematic%20Note.pdf.
- Beall, T., Massiot, E., Arsenaault, J.E., Smith, M.R., Hijmans, R.J., 2017. Global trends in dietary micronutrient supplies and estimated prevalence of inadequate intakes. *PLoS One* 12, 20.
- Bhat, Z.F., Kumar, S., Bhat, H.F., 2017. In vitro meat: A future animal-free harvest. *Crit. Rev. Food Sci. Nutr.* 57, 782–789.
- Biggs, S.D., 1990. A multiple source of innovation model of agricultural research and technology promotion. *World Dev.* 18, 1481–1499.
- Bijker, W.E., Hughes, T.P., Pinch, T.J., 1987. *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*. MIT Press, Cambridge, Mass.
- Bijker, W.E., Law, J., 1992. *Shaping Technology/Building Society: Studies in Sociotechnical Change*. MIT Press, Cambridge, Mass.
- Bollinedi, H.S.G.K., Prabhu, K.V., Singh, N.K., Mishra, S., Khurana, J.P., Singh, A.K., 2017. Molecular and functional characterization of GR2-R1 event based backcross derived lines of Golden Rice in the genetic background of a mega rice variety Swarna. *PLoS One* 12 e0169600.
- Bongoni, R., Basu, S., 2016. A multidisciplinary research agenda for the acceptance of Golden Rice. *Nutr. Food Sci.* 46, 717–728.
- Brooks, S., 2010. *Rice Biofortification: Lessons for Global Science and Development*. Earthscan, London.
- Brooks, S., 2013. Biofortification: lessons from the Golden Rice project. *Food Chain* 3, 77–88.
- Callon, M., 1987. Society in the making: the study of technology as a tool for sociological analysis. In: Bijker, W.E., Hughes, T.P., Pinch, T.J. (Eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*. MIT Press, Cambridge, Mass, pp. 83–103.
- Callon, M., Law, J., 1997. After the individual in society: lessons on collectivity from science, technology and society. *Can. J. Sociol./Cahiers canadiens de sociologie* 22, 165–182.
- Campbell, B.M., Beare, D.J., Bennett, E.M., Hall-Spencer, J.M., Ingram, J.S.I., Jaramillo, F., Ortiz, R., Ramankutty, N., Sayer, J.A., Shindell, D., 2017. Agriculture production as a major driver of the Earth system exceeding planetary boundaries. *Ecol. Soc.* 22.
- Conway, G.R., Barbier, E.B., 2013. *After the Green Revolution: Sustainable Agriculture for Development*. Taylor & Francis.
- CSIRO, CGIAR ISPC Secretariat, 2017. *Agri-food System Innovation: Resetting the Conversation*. Workshop Report. Commonwealth Scientific and Industrial Research Organisation and the International Science and Partnership Council of the Consultative Group on International Agricultural Research, Canberra, Australia/CGIAR ISPC Secretariat, Rome, Italy.
- Cullather, N., 2010. *The Hungry World. America's Cold War Battle Against Poverty in Asia*. Harvard University Press, Cambridge, MA, USA and London, UK.
- Dame, J., Nusser, M., 2011. Food security in high mountain regions: agricultural production and the impact of food subsidies in Ladakh, Northern India. *Food Security* 3, 179–194.
- Das, R.J., 2002. The green revolution and poverty: a theoretical and empirical examination of the relation between technology and society. *Geoforum* 33, 55–72.
- Dosi, G., 1982. Technological paradigms and technological trajectories: A suggested interpretation of the determinants and directions of technical change. *Res. Policy* 11, 147–162.
- Eisenstein, M., 2014. Biotechnology: Against the grain. *Nature* 514, S55–S57.
- Enserink, M., 2008. Tough lessons from golden rice. *Science* 320, 468–471.
- Evenson, R.E., Gollin, D., 2003. Assessing the impact of the Green Revolution, 1960 to 2000. *Science* 300, 758–762.
- Fatimah, Y.A., Arora, S., 2016. Nonhumans in the practice of development: Material agency and friction in a small-scale energy program in Indonesia. *Geoforum* 70, 25–34.
- Freebairn, D.K., 1995. Did the green revolution concentrate incomes? A quantitative study of research reports. *World Dev.* 23, 265–279.
- GAIN, 2018. Fortification assessment coverage toolkit (FACT) survey in Afghanistan, 2017. Global Alliance for Improved Nutrition (GAIN), Geneva, Switzerland.
- Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Res. Policy* 31, 1257–1274.
- Glover, D., 2017. Connecting agriculture to better nutrition in South Asia: Innovation as a process of socio-technical change, LANSa Working Paper 2017-16. Institute of Development Studies, Brighton.
- Gómez, M.I., Barrett, C.B., Raney, T., Pinstrup-Andersen, P., Meerman, J., Croppenstedt, A., Carisma, B., Thompson, B., 2013. Post-green revolution food systems and the triple burden of malnutrition. *Food Policy* 42, 129–138.
- Gómez, M.I., Ricketts, K.D., 2013. Food value chain transformations in developing countries: Selected hypotheses on nutritional implications. *Food Policy* 42, 139–150.
- Gopalan, C., 2013. The changing nutrition scenario. *Indian J. Med. Res.* 138, 392–397.
- Gulati, S., Misra, A., 2014. Sugar intake, obesity, and diabetes in India. *Nutrients* 6, 5955–5974.
- Hall, A., n.d. Transformative innovation: What do applied innovation study solutions look like? CSIRO, Canberra, Australia.
- Hallström, E., Gee, Q., Scarborough, P., Cleveland, D.A., 2017. A healthier US diet could reduce greenhouse gas emissions from both the food and health care systems. *Clim. Change* 142, 199–212.
- Harwood, J., 2012. *Europe's Green Revolution and Others Since: The Rise and Fall of Peasant-friendly Plant Breeding*. Taylor and Francis, Hoboken, NJ, USA.
- Haskell, M.J., 2012. The challenge to reach nutritional adequacy for vitamin A: β -carotene bioavailability and conversion—evidence in humans. *Am. J. Clin. Nutr.* 96, 1193S–1203S.
- Hazell, P.B.R., 2009. *The Asian Green Revolution*, IFPRI Discussion Paper. International Food Policy Research Institute, Washington, DC, USA.
- Headey, D.D., Hoddinott, J., 2016. Agriculture, nutrition and the green revolution in Bangladesh. *Agric. Syst.* 149, 122–131.
- Hughes, T.P., 1987. The evolution of large technological systems. In: Bijker, W.E., Hughes, T.P., Pinch, T.J. (Eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*. MIT Press, Cambridge, Mass, pp. 51–82.
- Hussain, S., Maqsood, M.A., Miller, L.V., 2012a. Bioavailable Zinc in grains of bread wheat varieties of Pakistan. *Cereal Res. Commun.* 40, 62–73.
- Hussain, S., Maqsood, M.A., Rengel, Z., Khan, M.K., 2012b. Mineral bioavailability in grains of Pakistani bread wheat declines from old to current cultivars. *Euphytica* 186, 153–163.
- IFPRI, 2016. *Global Nutrition Report 2016, From Promise to Impact: Ending Malnutrition by 2030*. International Food Policy Research Institute, Washington, DC, USA.
- IFPRI, 2018. *2018 Global Food Policy Report*. International Food Policy Research Institute, Washington, DC, USA.
- Jansen, K., Gupta, A., 2009. Anticipating the future: “Biotechnology for the poor” as unrealized promise? *Futures* 41, 436–445.
- Jewitt, S., Baker, K., 2007. The Green Revolution re-assessed: Insider perspectives on agrarian change in Bulandshahr District, Western Uttar Pradesh, India. *Geoforum* 38, 73–89.
- Johnson, C., Praveen, D., Pope, A., Raj, T.S., Pillai, R.N., Land, M.A., Neal, B., 2017. Mean population salt consumption in India: a systematic review. *J. Hypertens.* 35, 3–9.
- Joseph, N., Nelliyan, M., Rap, S., Babu, Y.P.R., Kotian, S.M., Ghosh, T., Singh, M., 2015. Fast food consumption pattern and its association with overweight among high school boys in Mangalore City of Southern India. *J. Clin. Diagnostic Res.* 9, LC13–LC17.
- Kadiyala, S., Morgan, E.H., Cyriac, S., Margolies, A., Roopnaraine, T., 2016. Adapting agriculture platforms for nutrition: A case study of a participatory, video-based agricultural extension platform in India. *PLoS One* 11 e0164002.
- Khan, S.H., Talukder, S.H., 2013. Nutrition transition in Bangladesh: is the country ready for this double burden. *Obes. Rev.* 14, 126–133.
- Klerkx, L., Hall, A., Leeuwis, C., 2009. Strengthening Agricultural innovation capacity: Are innovation brokers the answer?
- Kulkarni, V.S., Kulkarni, V.S., Gaiha, R., 2017. “Double burden of malnutrition”: Reexamining the coexistence of undernutrition and overweight among women in India. *Int. J. Health Serv.* 47, 108–133.
- Kuriyen, V., 2007. India's milk revolution: Investing in rural producer organisations. In: Narayan-Parker, D., Glinskaya, E.E. (Eds.), *Ending Poverty in South Asia: Ideas that*

- Work. World Bank, Washing DC, USA, pp. 37–67.
- Latham, M.E., 2010. *The Right Kind of Revolution: Modernization, Development, and U.S. Foreign Policy from the Cold War to the Present*. Cornell University Press.
- Latour, B., 2005. *Reassembling the Social: An Introduction to Actor-network Theory*. Oxford University Press, Oxford.
- Leach, M., Scoones, I., Stirling, A., 2010. *Dynamic Sustainabilities: Technology, Environment, Social Justice*. Routledge, London.
- Lewis, D., 2012. Is innovation essential for development work? Poverty matters blog, The Guardian, 25 July. Available at: <https://www.theguardian.com/global-development/poverty-matters/2012/jul/25/innovation-development-funding-capability> (accessed 30 March 2018).
- Long, N.E., 2001. *Development Sociology: Actor Perspectives*. Routledge, Abingdon, UK.
- Lundvall, B.Å., 2007. National innovation systems—analytical concept and development tool. *Industry Innovation* 14, 95–119.
- Ma, X., Mau, M., Sharbel, T.F., 2018. Genome editing for global food security. *Trends Biotechnol.* 36, 123–127.
- MacKenzie, D., Wajcman, J., 1999. *The Social Shaping of Technology*, second ed. Open University Press, Buckingham.
- Meenakshi, J.V., 2016. Trends and patterns in the triple burden of malnutrition in India. *Agric. Econ.* 47, 115–134.
- Misra, A., Singhal, N., Sivakumar, B., Bhagat, N., Jaiswal, A., Khurana, L., 2011. Nutrition transition in India: Secular trends in dietary intake and their relationship to diet-related non-communicable diseases. *J. Diabetes* 3, 278–292.
- Mistry, S.K., Puthussery, S., 2015. Risk factors of overweight and obesity in childhood and adolescence in South Asian countries: a systematic review of the evidence. *Public Health* 129, 200–209.
- Møller, M., 2016. Innovation for Development. The Blog, Huffington Post, 2 May. Available at: https://www.huffingtonpost.com/michael-moller/-innovation-for-developmen_b_9167674.html (accessed 30 March 2018).
- Muthayya, S., Rah, J.H., Sugimoto, J.D., Roos, F.F., Kraemer, K., Black, R.E., 2013. The global hidden hunger indices and maps: An advocacy tool for action. *Plos One* 8.
- Owen, R., Macnaghten, P., Stilgoe, J., 2012. Responsible research and innovation: From science in society to science for society, with society. *Sci. Public Policy* 39, 751–760.
- Padulosi, S., Mal, B., King, O., Gotor, E., 2015. Minor millets as a central element for sustainably enhanced incomes, empowerment, and nutrition in rural India. *Sustainability* 7, 8904.
- Parasar, R., Bhavani, R.V., 2016. Review of Agri-Food Value Chain Interventions Aimed at Enhancing Consumption of Nutritious Food by the Poor: India. LANSa Working Paper 2016-8. LANSa, Brighton, UK.
- Patel, R., 2012. The long green revolution. *J. Peasant Stud.* 40, 1–63.
- Perez, C., 2010. Technological revolutions and techno-economic paradigms. *Camb. J. Econ.* 34, 185–202.
- Perkins, J.H., 1997. *Geopolitics and the Green Revolution: Wheat, Genes and the Cold War*. Oxford University Press, Oxford, UK.
- Pingali, P., 2012. Green revolution: impacts, limits, and the path ahead. *Proc. Natl. Acad. Sci.* 109, 12302–12308.
- Qaim, M., 2017. Globalisation of agrifood systems and sustainable nutrition. *Proc. Nutr. Soc.* 76, 12–21.
- Rajshekhhar, S.C., Raju, S., 2017. Introduction of Millets in PDS: Lessons from Karnataka. LANSa MSSRF Report, June. MSSRF, Chennai, India. <http://59.160.153.185/library/sites/default/files/Millets%20in%20PDS%20Study.pdf>.
- Reardon, T., 2015. The hidden middle: the quiet revolution in the midstream of agrifood value chains in developing countries. *Oxford Rev. Econ. Policy* 31, 45–63.
- Richards, P., 1985. *Indigenous Agricultural Revolution*. Unwin Hyman, London.
- Rogers, E.M., 2003. *Diffusion of Innovations*, fifth ed. Free Press, New York.
- Saha, M., 2013. Food for Soil, food for people: Research on food crops, fertilizers, and the making of “modern” Indian agriculture. *Technol. Culture* 54, 289–316.
- Saha, M., Schmalzer, S., 2016. Green-revolution epistemologies in China and India: technocracy and revolution in the production of scientific knowledge and peasant identity. *BJHS Themes* 1, 145–167.
- Shankar, B., Agrawal, S., Beaudreault, A.R., Avula, L., Martorell, R., Osendarp, S., Prabhakaran, D., McLean, M.S., 2017. Dietary and nutritional change in India: implications for strategies, policies, and interventions. *Ann. N. Y. Acad. Sci.* 1395, 49–59.
- Sirajul Islam, M., Abid-ul-Kabir, M., Chakraborty, B., Hossain, M., 2017. Review of agrifood chain interventions aimed at enhancing consumption of nutritious food by the poor: Bangladesh, LANSa Working Paper. LANSa, Brighton, UK.
- Sovacool, B.K., Hess, D.J., 2017. Ordering theories: Typologies and conceptual frameworks for sociotechnical change. *Social Stud. Sci online first*, 0306312717709363.
- Sozer, N., Kokini, J.L., 2009. Nanotechnology and its applications in the food sector. *Trends Biotechnol.* 27, 82–89.
- Spielman, D.J., Pandya-Lorch, R., 2009. *Millions Fed: Proven Successes in Agricultural Development*. International Food Policy Research Institute, Washington, DC, USA.
- Spiker, M.L., Hiza, H.A.B., Siddiqi, S.M., Neff, R.A., 2017. Wasted food, wasted nutrients: nutrient loss from wasted food in the United States and comparison to gaps in dietary intake. *J. Acad. Nutr. Dietetics* 117, 1031–1040.e1022.
- Stein, A.J., 2010. Global impacts of human mineral malnutrition. *Plant Soil* 335, 133–154.
- Centre, S.T.E.P.S., 2010. *Innovation, Sustainability, Development: A New Manifesto*. The STEPS Centre, Brighton, UK.
- Stilgoe, J., Owen, R., Macnaghten, P., 2013. Developing a framework for responsible innovation. *Res. Policy* 42, 1568–1580.
- Stirling, A., 2009. Direction, Distribution and Diversity! Pluralising Progress in Innovation, Sustainability and Development, STEPS Working Paper. The STEPS Centre, Brighton, UK.
- Stirling, A., 2011. Pluralising progress: From integrative transitions to transformative diversity. *Environ. Innovation Societal Transitions* 1, 82–88.
- Stuart, T., 2009. *Waste: Uncovering the Global Food Scandal*. W. W. Norton.
- Subramanian, K., 2015. *Revisiting the Green Revolution: Irrigation and food production in twentieth-century India*. PhD thesis. King's College, London.
- Ton, G., Vellema, S., Ge, L., 2014. The triviality of measuring ultimate outcomes: acknowledging the span of direct influence. *IDS Bull.* 45, 37–48.
- Vasavi, A.R., 2009. Suicides and the making of India's agrarian distress. *South African Rev. Sociol.* 40, 94–108.
- Vasavi, A.R., 2012. *Shadow Space: Suicides and the Predicament of Rural India*. Three Essays Collective, Gurgaon, IN.
- Vlek, P.L.G., Khamzina, A., Tamene, L., 2017. *Land degradation and the Sustainable Development Goals: Threats and potential remedies*, CIAT Publication No. 440. International Center for Tropical Agriculture (CIAT), Nairobi, KE.
- WHO, 2018. *Global Health Observatory Data. NCD Mortality and Morbidity*. World Health Organisation, Geneva, CH.